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A Review on Bacterial Degradation of Textile Dyes

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ABSTRACT

A variety of synthetic dyestuffs were released from the textile industry and made a threat to environmental safety. Azo dyes account for the majority of all dyestuffs, produced because they are extensively used in the textile, paper, food, leather, cosmetics and pharmaceutical industries. Existing effluent treatment procedures are unable to remove various dyes completely from effluents because of their color fastness, stability and resistance to degradation. Bacterial decolorization and degradation of dyes under certain environmental conditions. The method of treatment, as these are inexpensive, eco-friendly and can be applied to wide range of such dyes. This review mainly focuses on the different of bacterial decolorization processes and find a solution to decolorization of dyes and dye effluents.

Keywords: Dye decolorization, bacterial decolorization, dye effluent.

INTRODUCTION

A dye is a synthetic chemical used to impart color to materials of which it becomes an integral part. Dyes are carbon based organic compounds while pigments are normally inorganic compounds, often involving heavy toxic metals (Balakrishnan *et al*. 2008). Dyes are classified to their application and chemical structure. They are composed of a group of atoms responsible for the dye color, called chromophores, as

well as an electron withdrawing or donating substituents that cause or intensify the color of the chromophores, called auxophores.

Dyes are of various types based on their dissociation in aqueous solutions i.e. acid dyes, direct reactive dyes (anionic), basic dyes (cationic) and disperse dyes (nonionic). They are used on several substrates in food, cosmetics, paper, plastic and textile industries. Solutions retain them by physical adsorption by making compounds with metals and salts using covalent bonds.

A very small amount of dye in water (10-50 mg L-1) affects the aesthetic value, transparency of water and gas solubility of water bodies. The presence of even very low concentrations of dyes in effluent is highly visible and degradation products of these textile dyes are often carcinogenic (Kim *et al*., 2003). Further, the adsorption of light by these textile dyes creates problems for photosynthetic aquatic plants and algae (Singh and Singh, 2006). These reactive dyes are a highly water-soluble polyaromatic molecule, which means they do not adsorb to solids and are prevalent in high concent ration in the effluents (Ganesh *et al*., 1994).

Rapid urbanization and industrialization has lead to a vast release of waste to the environment adding to the pollution load. Majority of colored effluents contains dyes released from textile, dyestuff and dyeing industries. India's dye industries produces every type of dyes and pigments. Production of yestuff and pigments in India is close to 80,000 tones. the textile industry is one of the greatest generators of iquid effluent pollutants dye to the high quantities of water used in the dyeing processes. The traditional textile finishing industry consumes about 100 L of water to process about 1 Kg of textile materials cell membranes. The chemical structure of dyes in general is comprised of a conjugated system of double bonds and aromatic rings. The major classes of dyes have anthroquinoid, indigoid and azo aromatic structures Several methods were adapted for the reduction of azo dyes to achieve decolorization like physical, chemical and biological. Physical treatment methods such as screening, sedimentation and skimming remove floating objects. Chemical treatment methods such as Precipitation, pH adjustment, Coagulation etc., to remove toxic materials and colloidal impurities In case of enzymatic remediation of azo dyes, azo reductases and laccases seem to be the most promising enzymes. Azo-reductases catalyze the reaction only in presence of reducing equivalents like FADH and NADH. Most of the Azo dye have sulphonate substituent groups and a high molecular weight and they are unlikely to pass through

REVIEW OF LITERATURES

This reviews mainly focused on various bacterial species have been used for decolorizaion of dye effluents from the various researchers in their work in world.

Laccases are involved in the biodegradation of lignins, which constitute the main noncarbohydrate component in wood and are among the most abundant groups of biopolymers in the biosphere (Elias Abdulla, *et al*. 2000). Faryal and Hameed (2005) carried out the textile effluent analysis for presence of Mn, Zn, Mg etc. and reported subsequent decolourising

bacteria. Guendy (2007) discovered a method for treatment of wide conc. range of dye waste water through ozonization. Khadijah (2009) repoted 1540 bacterial isolates and screened for their ability to degrade selected azo dyes.[1 – 11]

Sapna Kochher & Sandeep Kumar (2012) studied about screening for potential textile dye decolorizing bacteria. The result of this study suggesed a great potential for bacteria to be used remove colour from dye wastewaters. The bacterial species used in carrying out the decolorization of dyes in the study were isolated from the textile dye industry waste effluent. The batcterial strain Bacillus sp. Showed decolorizing activity through a degradation mechanism rather than adsorption. This study has established that the bacteria are adaptive in nature and can degrade contaminants.[12].

Leena. R and Selva Raj. D (2008) studied about Bio-decolourization of textile effluent containing Reactive Black-B by effluent – adapted and non- adapted bacteria. The used five effluent adapted bacteria namely (1).Alcaligenes sp, (2).Eubacterium sp,(3). Arthrobacter sp. (4). Pseudomonas aeruginosa & (5). Bacillus sp. The also used four effluent non-adapted bacteria namely (1).Kluyvara ascorbata, (2). Bacillus sp, (3).Pseudomonas sp & (4).Pasteurella sp.for decolourization in ten days. Effluent-adapted bacillus sp. gave 35.68% reduction in colour wheresas the non-adapted isolate of the same species showed 30.04% colour removal. Similarly, effluent-adapted P.aeruginosa showed 44.2% decolourization which was better than non-adapted Pseudomonas sp. (41.73%).[13-27].

Kothari R. K (2002) and Kothari C. R (2006) reported the effect of static and shaking conditions on decolorization of various textile dyes. Their results suggested that more decolorization is achieved under static culture condition compared to shake flask condition.[29-31]

According to the concept of combined anaerobic-aerobic treatment, azo dyes should be removed from the water phase by anaerobic reduction followed by aerobic oxidation of the dyes' constituent aromatic amines. The anaerobicaerobic reactor studies show that a generally high extent of color removal can be obtained, and several studies furthermore provide evidence for removal of aromatic amines. Combined anaerobic-aerobic treatment therefore holds promise as a method to completely remove azo dyes from wastewater[32] (Naimabadi *et al*., 2009)

The ability of two bacterial strains, the Gram –negative Alcaligenes faecalis and the Gram-positive Rhodococcus erythropolis to decolorize the monoazo dye Acid orange were studied with different initial dye concentrations by Mutafov *et al*. (2007).[33]

The diazo dye Reactive yellow 84A was efficiently degraded by a novel bacterial strain Exiguobacterium sp. Analytical techniques like HPLC, GCMS, and FTIR demonstrated that degradation of dye resulted with significant reduction of phytotoxicity, confirming the environmentally safe nature of the degradation metabolites[34] (Dhanve *et al*., 2009).

Aerobic Decolorization Process

Activated sludge treatment of wastes is effective and highly economic system for reducing organic pollutants in wastewater.

However, aerobic treatment of azo dye wastes has proven ineffective in most cases, but it is often the typical 12 method of treatment used today[35] (Edwards, 2000; Yang *et al.*, 1998).

Table 1. Different physical and chemical methods for dye removal from textile effluent with its advantages and disadvantages.[28] (Robinson *et al*, 2002b)

Physical/chemical method	**Advantages**	**Disadvantages**
Fentons reagent	Effective decolaration of soluble and insoluble dyes	Sludge generation\
Ozonation	Applied in gaseous state, no alteration of volume	Short half life (20 min)
Photochemical	No sludge production	Formation of by-products
Sodium hypochlorite	Initiates and accelerate azo bond Cleavage	Release of aromatic amines
Electrochemical destruction	Break-down compounds are nonhazardous	High electricity consumption
Activated carbon	Good removal of wide variety of dyes	Very expensive
Peat	Good adsorbent due to cellular structure	Specific surface area for adsorption are lower than activated carbon
Wood chips	Good sorption capacity for acidic dyes	Require long retention time
Silica gel	Effective for basic dye removal	Side reactions prevent commercial application
Membrane filtration	Removal all types of dyes	Concentrated sludge production
Ion-exchange	No adsorbent loss due to regeneration	Not effective for all dyes
Irradiation	Effective oxidation at laboratory scale	Requires high concentrations of dissolved oxygen
Electrokinetic coagulation	Economically feasible	High sludge production

The ability of bacteria to metabolize azo dyes has been investigated by a number of research groups. Under aerobic conditions azo dyes are not readily metabolized, the intermediates formed by the degradative steps resulted in disruption of metabolic pathways and the dyes were not actually mineralized. Under anaerobic conditions, such as anoxic sediments, soluble, cytoplasmic reductases, known as azo reductases, reportedly produce colorless aromatic amines which can be toxic, mutagenic, and possibly carcinogenic[36].

The wastewaters from textile industry contain various dyes. The bacteria should exhibit decolorizing ability for a wide

range of dyes. Isolating such microorganisms proved to be a difficult task. To gain a widespread reception, efforts to isolate bacterial cultures capable of degrading azo dyes started in the 1970s with reports of a Bacillus subtilis[37]. followed by numerous bacteria: Pseudomonas spp. were isolated from an anaerobic-aerobic dyeing house wastewater treatment facility as the most active azo-dye degraders[38,31] Chang *et al*.[39] used the extracellular metabolites of a dye-decolorizing strain, *Escherichia coli* strain NO3**,** as a biostimulator to entice E. coli strain NO3 into a beneficial mode of metabolism for an economically feasible decolorization. Technical process was designed to decolorize textile wastewaters by sulfate reducing bacteria[40].

Much of the work undertaken in dye degradation has involved the decolorization of azo dyes. An aerobic azo dye degradation by several bacterial strains capable of using the dye as the sole source of carbon and nitrogen has been reported[41]. Anthraquinone-based dyes are highly resistant to degradation due to their fused aromatic structures. Some anthraquinone dyes undergo decolorization and degradation by Bacillus subtilis[42]. Walker and Weatherly[43] reported degradation of an acid anthraquinone dye by three strains of Pseudomonas and Bacillus.

Physico-chemical methods are applied for the treatment of many textile dye effluents achieving high dye removal efficiencies[44]. On the other hand, in recent years there is a tendency to use biological treatment systems to treat dye-bearing wastewaters[45]. The recalcitrant nature of azo dyes, together with their toxicity to microorganisms, makes aerobic treatment difficult. On the other hand, a wide range of azo dyes is decolorized anaerobically[46, 47;48,49].

The textile dye (Orange 3R) is degradable under aerobic conditions with a concerted effort of bacteria isolated from textile dye effluent. Nutrients (carbon and nitrogen sources) and physical parameters (pH, temperature and inoculum size) had significant effect on dye decolorization. Pseudomonas sp. showed highest decolorization of Orange 3R dye effectively during optimization and more interesting Pseudomonas sp. showed consist ent decolorization of textile dye (Orange 3R) throughout the study.[50].

Recent fundamental work has revealed the existence of a wide variety of micro organisms capable of decolourising a wide variety of dyes. Many microorganisms belonging to different taxonomic groups of Bacteria, Fungi, Actinomycetes and Algae have been reported for their ability to decolourise azo dyes. Bacterial degradation of these dyes requires by their intracellular uptake while the fungi degrade these by extracellular enzymes[51].

Recently number of studies focused the some bacteria and fungi, which are able to biodegrade and bioadsorb the dyes in textile industry ef fluent[52]. The organisms used in most of the study were Staphylococcus sp, E.coli, Bacillus sp, Clostridium sp, and Pseudomonas sp in bacteria[53]. Microbial decolourization of azo dyes has been reached by sequential anaerobic and aerobic conditions[54].

Azo dyes contain at least one nitrogen-nitrogen (-N=N-) double bond, however many different structures are possible[55]. Mono-azo dyes have only one -

N=N- double bond, while di-azo and tri-azo dyes contain two and three - N=N- double bonds respectively. The azo groups are generally connected to benzene and naphthalene rings, but can also be attached to aromatic heterocycles or enolizable aliphatic groups[55]. These side groups are necessary for imparting the color of the dye, with many different shades and intensities being possible[56].

Eighty to ninety five percent of all reactive dyes are based on the azo chromogen[57,58]. Reactive dyes are colored compounds that contain one or two functional groups capable of forming covalent bonds with the active sites in fibers. A carbon or phosphorous atom of the dye molecule will bond to hydroxyl groups in cellulose, amino, thiol, and hydroxyl groups in wool, or amino groups in polyamides[57,59]. Most fiber-reactive azo dyes are used for dyeing cellulosic materials, such as cotton, and are a major source of dye wastes in textile effluents. Between 20-50% of the reactive dye used by the textile industry is lost in exhaust and wash water[60]. Fiber-reactive azo dyes exhibit a high wet-fastness, due to their ability to covalently bond to substrates. However, dyes that hydrolyze in solution prior to bonding to a substrate are often lost in the washing processes[61].

Various studies have showed that biodegradation by microorganisms is a promising approach for treating effluents containing dyes[62]. The effectiveness of microbial decolorization depends on the adaptability and the activity of selected microorganisms[63]. Many microorganisms have been reported to degrade dyes; these include bacteria[64,65], filamentous fungi [66,67,68], yeasts[69,70,71] actinomycetes[72] and algae[73]. It is known that many strains of bacteria reductively cleave some dyes producing aryl amines under anaerobic conditions, but these dyes are difficult to degrade aerobically[64].

Reactive dyes are the both highly water soluble due to a high degree of sulfonation and non-degradable under the typical aerobic conditions found in conventional biological treatment systems[74,75]. In contrast to the wealth of information regarding the transformation of azo compounds, relatively little is known about the transformation of complex reactive textile azo dyes despite the fact that their use has increased due to the worldwide increase in cotton use.

BIOREMEDIATION

Bioremediation is the use of biological systems for the reduction of pollution from air, aquatic or terrestrial systems. Microorganisms and plants are the biological systems which are generally used for this purpose. Biodegradation with microorganisms is the most frequently occurring bioremediation option. Microorganisms can break down most compounds for their growth and/or energy needs. These biodegradation processes may or may not need air. In some cases, metabolic pathways which organisms normally use for growth and energy supply may also be used to break down pollutant molecules. In these cases, known as metabolism, the microorganisms do not benefit directly, but researchers have taken advantage of this phenomenon and use it for bioremediation. Complete degradation, often termed mineralization, ultimately yields

water and either carbon dioxide or methane[76,77]. Incomplete biodegradation will yield breakdown products which may or may not be less toxic than the original pollutant.

Thus, bioremediation addresses the limitations of these conventional techniques by bringing about the actual destruction of many organic contaminants at reduced cost. As a result, over the last two decades, bioremediation has grown from a virtually unknown technology to a technology that is considered for the cleanup of a wide range of contaminants.

A facultative Staphylococcus arlettae bacterium, isolated from an activated sludge process in a textile industry, was able to successfully decolourize four different azo dyes under microaerophilic conditions (decolourization percentage >97%). Further aeration of the decolourized effluent was performed to promote oxidation of the degradation products. The degradation products were characterized by FT-IR and UV–vis techniques and their toxicity with respect to Daphnia magna was measured. The amineconcentrations as well as the total organic carbon (TOC) levels were monitored during the biodegra-dation process. The presence of aromatic amine in the microaerophilic stage and its absence in theaerobic stage indicated the presence of azoreductase activity and an oxidative biodegradation process,respectively. TOC reduction was 15% in the microaerophilic stage and 70% in the aerobic stage. Theresults provided evidence that, using a single Staphylococcus arlettae strain in the same bioreactor, thesequential icroaerophilic/aerobic stages were able to form aromatic amines by reductive break-down ofthe azo bond and to oxidize them into non-toxic metabolites[78].

Acid red decolorizing bacteria was isolated and identifi ed as *Acinetobacter radioresistens*. The effect of operationparameters such as medium composition, pH, temperature, dye concentration on the decolorization of acid red wasstudied and the products of degradation were analyzed and confi rmed using LC–MS analysis. The reductive cleavageof azo bond was catalyzed by oreductase, the key enzyme for the azo dye degradation. The catalytic reductionof acid red 37 by purifi ed azoreductase in the presence of NADH as electron donor was studied and the products of degradation were determined as 1-{3-amino-5-[(aminoxy-determined as 1-{3-mino-5-inoxy) sulfonyl] phenyl}ethanol and 7,8-di diamino-3 [(aminoxy)sulfonyl]naphthalene-1-ol.[79]

CONCLUSION

From the forgoing evidences of varius review of litreatures which were completed by various reseserchers of the world, we come into the following conclusions.

1. Bacteria is a cheaper and better environment friendlier alternative for colour removal in textile dye effluents.
2. Biological treatment has been effective in reducing dye house effluents and when used properly has a lower operating cost than other remediation decolorization process.
3. Microbial consortium has become a very good source for the textile industry in getting rid of theireffluent problem by Biodegradation and Decolorization

process. Since they are cost effective and efficient it is highly recommended for the industries in making use of the consortium for the proper disposal of textile effluents.

ADVANDAGES OF BACTERIAL DECOLORIZATION PROCESSES

1. This treatment uses no chemicals
2. The consortium disposes no harmful matters into the environment. and The process eliminates chemical processing and vapour.
3. No energy used and consequently zero carbon process. Also worth carbon credit and no complicated plants needed

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REFERENCES

1. Shenai, V. A. Chemical index international. *Chemical weekly*. 145-149 (1994).
2. Guendy, H. R. Ozone treatment of textile waste water relevant to toxic effect elimination in marine environment. *Egyptian Journal of Aquatic Research*. 98-115 (2007).
3. Kapdan, K.I., F. Kargi, G. McMullan and R. Marchant. Effect of environmental conditions on biological decolorization of textile dyestuff by C. versicolor. *Enzyme and Microbial Technoloy*, 26, 381-387 (2000).
4. Faryal, R., Hameed, A. Isolation and characterization of various fungal strains from textile effluent for their use in bioremediation. *Pak. J. Bot*.; 1003-1008 (2005).
5. Khadijah,O., Lee,K.K., Mohd Faiz F., Abdullah. Isolation, screening and development of local bacterial consortia with azo dyes decolourising capability. *Malaysian Journal of Microbiology*.;25-32 (2009).
6. Balakrishnan, M., S. Arul Antony, S. Gunasekaran, R.K. Natarajan. Impact of dyeing industrial effluents on the ground water quality in Kancheepuram (India). *Indian Journal of science and Technology*. Vol.1 No.7, B-117-123 (2008).
7. Kim, S., C. Park, T.H. Kim, J. Lee, S.W. Kim. COD reduction and decolorization of textile effluents using a combined process. *J. Biosci. Bioeng*., 95;;102-105 (2003).
8. Singh, V.K., Singh, J. Toxicity of industrial wastewater to the auatic plant Lemna minor. L. *J. Environmental Biol*., 27;; 385-390 (2006).
9. Ganesh, R., G.D. Boardman and W.C. Tincher. Fate of azo dyes in sluges. *Water Res*., 28, 1367-1376 (1994).
10. Wiegel,J., Zhang,X., Wu,Q. Anaerobic dehalogenation of hydroxylated polychlorinated biphenyls by Desulfitobacterium dehalogenans. Applied and Environmental Microbiology., 2217-2221 (1999).
11. Yatome, C., Ogawa, T., Koga, D. and Idaka, E. Biodegradation of Azo and triphenylmethane dyes by Pseudomonas pseudomallei. 13na. *J. Society. dyers colorist*.; 97:166-169 (1981).
12. Sapna Kochher and Sandeep Kumar, “Screening For Potential Textile Dye Decolorizing Bacteria”, “*International Journal for Science and Emerging Technologies with Latest Trends*” 2(1): 36-48 (2012).

13. Abadulla E, Robra KH, Gubitz G, Silva L, Cavaco-Paulo A. Enzymatic de-colourrrization of textile dyeing effluents. *Textile Res. J*. 70: 409-414 (2000).
14. Boer CG, Obici L, Sourza CG, Piralta, RM. Decolourization of synthetic dyes by solid state cultures of *Lentinula (Lentinus) edodes* producing manganese peroxidase as the main lignolytic enzyme. *Bioresour. Technol*. 94: 107-112 (2004).
15. Chen KC, Huang WT, Wu JY, Houng JY. Microbial decolourization of azo dyes by *Proteus mirabilis. J. Ind. Microbiol. Biotechnol*. 23: 686-690 (1999).
16. Hao OJ, Kim H, Chang PC. Decolourization of wastewater. *Crit. Rev. Environ. Sci. Technol*. 30: 449-505 (2000).
17. Maier J, Kandelbauer A, Erlacher A, Cavaco-Paulo A, Gubitz GM. A new alkalithermostable azo reductase from *Bacillus sp*. Strain SF. *Appl. Environ. Microbiol*. 70(2): 837- 844 (2004).
18. McMullan G, Meehan C, Conneely A, Kirby N, Robinson T, Nigam P, Banat IM, Marchant R Smyth WF. Microbial decolourization and degradation of textile dyes. *Appl. Microbiol. Biotechnol*. 56: 81-87 (2001).
19. Moosvi S, Keharia H, Madamwar D. Decolourization of textile dye Reactive Violet 5 by a newly isolated bacterial consortium RVM 11.1. *World J. Microbiol. Biotechnol* 21:667-672 (2005).
20. Olukanni OD, Osuntoki AA, Gbenle GO. Textile effluent biodegradation potentials of textile effluent-adapted and non-adapted bacteria. *Afr. J. Biotechnol*. 5(20): 1980-1984 (2006).
21. Oranusi NA, Ogugbue CJ. Effect of pH and nutrient starvation on biodegradation of azo dyes by *Pseudomonas* sp. *J. Appl. Sci. Environ. Manage*. 9 (1): 39-43 (2005).
22. Pearce CI, Lioyd JR, Guthrie JT. The removal of colour from Textile wastewater using whole bacterial cells: a review. *Dyes Pigments* 58: 179-196 (2003).
23. Robinson T, McMullan G, Marchant R, Nigam P. Remediation of dyes in textile effluent: A critical review on current treatment technologies with a proposed alternative. *Bioresour Technol*. 77(3): 247-255 (2001).
24. Senan RC, Abraham TE. Bioremediation of textile azo dyes by aerobic bacterial consortium. (Aerobic degradation of selected azo dyes by bacterial consortium). *Biodegradation*, 15(4): 275-280 (2004).
25. Stolz A. Basic and applied aspect in the microbial degradation of azo dyes. *Appl. Microbiol. Biotechnol*. 56: 69-80 (2001).
26. Weisburger JH. Comments on the history and importance of aromatic and heterocyclic amines in public health. Mutat. Res. 506/507: 9-20 (2002).
27. Willetts JRM, Ashbolt NJ. Understanding anaerobic decolourization of textile dyes wastewater: mechanism and kinetics. *Water Sci. Technol*. 42 (1-2): 409- 416 (2000).
28. Rabinson, T., Chandran, B., Nigam, P. Removal of dyes from an artificial textile dye effluent by two agricultural residue, corncob and barley husk. *Environment Int*. (2002b).
29. Kothari C. R. Ph. D. thesis. Microbial degradation of organopollutants, Saurashtra University, Rajkot (2006).

30. Kothari, R.K., Kothari, C.R., and Pathak, S.J. Microbial decolorization and degradation of textile dyes Golden HR and Magenta HB. *Asian J. Microbiol. Biotehnol. Environ. Sci*. 7(2):1-5 (2005).
31. Kothari R.K. Microbial degradation of synthetic dyes-Ph.D. thesis. Saurashtra University, Rajkot, Gujarat, India (2002).
32. Naimabadi, A., Movahendian Attar, Shahsavani, A. Decolorization and biological degradation of azo dye reactive red 2 by anaerobic/aerobic sequential process. *Iran J. Environ. Health. Sci. Eng.*, 6 (2):67 -72 (2009).
33. Dhanve R.S., Kalyani D.C., Phugare S.S., Jadhav J.P. Coordinate action of exiguobacterial oxidoreductive enzymes in biodegradation of reactive yellow 84A dye. *Biodegradation* 20: 245-255 (2009).
34. Mutafov, S., Avramova, T., Stefanova, L., Angelova, B. Decolorization of acid orange by bacteria of different tinctorial type: a comparative study. *World J. Microbiol Biotechnol*. 23: 417-422 (2007).
35. Edward, R.T., Bilgehan, G., Aydin, A. Dying and chemical technology of textile fibers. *Journal of Supercritical Fluids.*12: 25-34 (2000).
36. McMullan, G., Meehan, C., Conneely, A., Kirby, N., Robinson, T.,Nigam, P., Banat, I.M., Marchant, R., & W.F. Smyth. Microbial decolorization and degradation of textile dyes. *Appl. Microbiol. Biotechnol*. 56:81-87 (2001).
37. Horitsu, H., Takada, M., Idaka, E., Tomoyeda, M. & T. Ogawa. Degradation of aminoazobenezene by Bacillus subtilis. *Eur. J. Appl. Microbiol*. 4:217-224 (1977).
38. Kothari, R.K., Kothari C.R. & Pathak, S.J. Microbial decolorization and degradation of textile dyes Golden HR and Magenta HB. *Asian J. Microbiol. Biotechnol. Environ. Sci*. 7(2):01-05 (2005).
39. Chang, J.S., Chen, B.Y, & Y.S. Lin. Stimulation of bacterial decolorization of azo dyes by extracellular metabolites from Escherichia coli strain NO_3. *Bioresource Technol*. 91:243-8 (2004).
40. Yoo, E.S. Kinetics of chemical decolorization of the azo dyes C.I. Reactive Orange 96 by Sulfide. *Chemosphere*. 47:925-931 (2002).
41. Coughlin, M.F, Kinkle, B.K, Tepper, A., & Bishop, P.L. Characterization of aerobic dye degrading bacteria and their activity in biofilms. Water. Sci. Technol. 36:215-20 (1997).
42. Itoh, K., Yatome, C. & T. Ogawa. Biodegradation of anthraquinone dyes by Bacillus subtilis. ull. Environ. *Contam. Toxicol*. 50:522-527 (1993).
43. Walker, M.G., & R.L. Weatherly. Biodegradation and biosorption of acid anthraquinone dye. Environ. Pollu. 108:219-223 (2000).
44. Vandevivere, P.C., Bianchi, R., & W. Verstraete. Treatment and reuse of wastewater from the textile wet-processing industry: Review of emerging technologies. *J. Chem. Technol. Biotech.* 72:289 -302 (1998).
45. Razo-Flores, E., Luijten, M., Donlon, B., Lettinga, G., and J. Field. Biodegradation of selected azo dyes under methanogenic conditions. *Water. Sci. Technol*. 36:65-72 (1997).

46. Banat, I.M., Nigam, P, Singh, D., & R. Marchant. Microbial decolorization of textile-dye containing effluents: a review. Bioresource Technol. 58:217-27 (1996).
47. Brown, D, & P. Laboureur. The degradation of dyestuffs: Primary bio-degradation under anaerobic conditions. *Chemosphere*. 12:397-404 (1983).
48. Cariell, C.M., Barclay, S.J., Naidoo, N., Buckley, C.A., Mulholland, D.A., & E. Senior. Microbial decolorization of a reactive azo dye under anaerobic conditions. *Water SA*. 21: 61-69 (1995).
49. Chinwetkitvanich, S., Tuntoolvest, M., and T. Panswad. Anaerobic decolorization of reactive dye-bath effluents by a two-stage UASB system with tapioca as a co-substrate. Water Res. 34:2223-2232 (2000).
50. M. Ponraj, K. Gokila and Vasudeo Zambare,.Bacterial Decolorization of Textile Dye - range 3R, Vol 2, Issue 1, pp 168-177 (2011).
51. Yoo ES, Libra J, Adrian L. Mechanism of decolourization of azo dyes in anaerobic mixed culture. *Journal of Environmental Engineering,* 127(9), 844-9 (2001).
52. Pearce CI, Lloyd JR, Guthrie JT. The removal of colour from textile waste water using whole bacterial cells: a review. *Dyes and Pigments*, 58, 179-196 (2003).
53. McMullan G, Meehan C, Connely A, Kirby N, Robinson, T, Marchant R, Smyth WF. Microbial decolourization and degradation of textile dyes. *Applied Microbiology and Biotechnology*, 56, 81-8 (2001).
54. Manjinder Singh Khehra, Harvinder Singh Saini, Deepak Kumar Sharma, Bhupnder Singh Chandha, Swapndeep Singh Chimni. Decolourization of various azo dyes by bacterial consortium. *Dyes and Pigments*, 67, 55-61 (2005).
55. Zollinger, H. Color Chemistry: Syntheses, *Properties and Applications of Organic Dyes and Pigments*. p. 496 (1991).
56. McCurdy, M.W. Chemical reduction and oxidation combinedwith biodegradation for the treatment of a textile dye wastewater. Masters Thesis, Virginia Polytechnic Institute and State University. p181 (1991).
57. Zollinger, H. Color Chemistry: Syntheses, *Properties and Applications of Organic Dyes and Pigments*. p. 496 (1991).
58. Edwards, J.C. Investigation of color removal by chemical oxidation for three reactive textile dyes and spent textile dye wastewater. Masters Thesis, Virginia Polytechnic Institute and State University. p.56 (2000).
59. Kirk, T.K., and Othmer, R. Encyclopedia of Chemical Technology, 2nd edi. Vol. 2, pp. 868-910. John Wiley, New York (1979).
60. Lewis, D.M. Coloration in the next century. *Rev. Prog. Color*. 29:23-28 (1999).
61. Lloyd, C.K. Anaerobic/aerobic degradation of a textile dye wastewater. Masters Thesis, Virginia Polytechnic Institute and State University. p.184 (1992).
62. Wesenberg, D., Buchon, F., & S.N. Agathos. Degradation of dye-containing textile effluent by the agaric white rot fungus Clitocybula dusenii. *Biotechnol. Lett*. 24:989-993 (2002).
63. Chen, K.C., Jane, Y.W., Liou, D.J., & J.H. Sz-Chwun. Decolorization of the

textile dyes by newly isolated bacterial strain. *Journal of Biotechnology*. 101:57-68 (2003).

64. Zimmerman, T., Kulla, H.G., & T. Leisinger. Properties of purified orange II azo reductase, the enzyme initiating azo dyedegradation by Pseudomonas KF46. *European J. Biochem*. 129: 197203 (1982).
65. Sani, R. and U. Banerjee. Decolorization of triphenylmethanes dyes and textile and dyestuff effluent by Kurthia sp. *Enz Microbial Technol*. 24: 433-437 (1999).
66. Gold, M.H. and M. Alic, Molecular biology of lignin-degrading basidomy-cete Phanerochaete chrysosporium. Microbiological Reviews. 57: 605-622 (1993).
67. Swamy, J. and J.A. Ramsay. The evaluation of white rot fungi in the decolorization of textile dyes. *Enzyme and Microbial Technology*.24:130-137 (1999).
68. Balan, D.S.L. and R.T.R. Monteiro. Decolorization of textile indigo dye by ligninolytic fungi. J. Biotechnol. 89:141-145 (2001).
69. Itoh, K., Kitade, Y. and C. Yatome. A pathway for biodegradation of an anthraquinone dye, C. I. Disperse Red 15, by a yeast strain *Pichia anomala*. *Bull. Environ. Contamin. Toxicol*. 6:413-418 (1996).
70. Martins, M.A., Cardoso, M.H., Queiroz, M.J., Ramalho, M.T., & A. M. Campos. Biodegradation of azo dyes by the yeast Candida zeylanoides in batch aerated cultures. Chemosphere. 38:2455-2460 (1999).
71. Meehan, C., Banat, I.M., McMullan, G., Nigam, P., Smyth, F., & R. Marchant. Decolorization of Remazol Black-B using thermotolerant yeast, Kluyveromyces marxianus IMB. Environ Int. 26:75-79 (2000).
72. Zhou, W. and W. Zimmermann. Decolorization of industrial effluents containing reactive dyes by actinomycetes. *FEMS Microbiol. Lett*. 107:157-162 (1993).
73. Dilek, F.B., Taplamacioglu, H.M. & E. Tarlan. Color and AOX removal from pulping effluents by algae. *Appl. Microbiol. Biotechnol.* 52:581-591 (1999).
74. Beydilli, I.M., Pavlostathis, S.G., and W. C. Tincher. Biological decolorization of the azo dye Reactive Red 2 under various oxidationreduction conditions. *Water Environ Res*. 72:698-705 (2000).
75. Kalyuzhnyi, S., Sklyar, V. Biomineralisation of azo dyes and their breakdown products in anaerobic-aerobic hybrid and UASB reactors. *Water Sci. Technol*. 41:23-30 (2000).
76. Alleman, B.C., & A. Lesson. *In situ* bioremediation of petroleum hydrocarbons and other organic compounds. Battelle Press, Columbus, Ohio (1999).
77. Alexander, M., & B.K. Lustigman. Effect of chemical structures on microbial degradation of substituted benzenes. *J. Agr. Food Chem* 14:410-413 (1996).
78. Artur Franciscon Elisangela , Zille Andrea ,Dias Gumaro Fabio , Ragagnin de enezesstiano, Durrant Lucia Regina , Cavaco-Paulo , Biodegradation of textile azo dyes by a facultative Staphylococcus arlettae strainVN-11 using a sequential microaerophilic/ aerobic rocess, International Biodeterioration & Biodegradation 63, 280–288 (2009).
79. Ramya M, Iyappan S, Manju A, Jiffe JS. Biodegradation and Decolorization of Acid Red by Acinetobacter radio-resistens. *J. Bioremed Biodegrad* (2010).